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Palynological and geochemical response to environmental changes in the Lower Cretaceous in the Outer Western Carpathians; a record from the Silesian unit, Czech Republic

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Abstract

Rich dinoflagellate cyst assemblages recorded from the Vendryne Formation, Tesin Limestone, and Hradiste Formation of the Silesian unit, Czech Republic are presented. The results of a qualitative and quantitative study of dinoflagellate cysts are presented and discussed. Age-assessment of the sediments based on 86 species suggests a Late Tithonian to Early Berriasian age for the Vendryne Formation and a Late Berriasian (Otopeta Ammonite Zone) to the basal part of the Late Valanginian (Verrucosum Ammonite Zone) age for the Tesin Limestone. Pelitic flyschoid sediments of the Hradiste Formation belong to the Late Valanginian – Early Hauterivian age. Quantitative palynological study and carbon isotope analysis were applied to understand the change from the grey clays to dark grey clays sedimentation. The dinoflagellate cyst assemblages show deposition in a shallow-sea environment. An increasing amount of sporomorphs towards the overlying layers (they are the most abundant in the Hradiste Formation) shows a growing supply of terrestrial material at the same time. The values of $\delta^{13}C$ increased significantly from a level of 0.43 or 0.75‰ to 1.81‰ in the Late Valanginian. This change probably indicates an increase in organic matter storage and perturbation of the carbon cycle connected with the dark grey clays sedimentation.

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1. Introduction

The sediments of the Silesian unit (Silesian Nappe) in the Outer (Flysch) Western Carpathians are characterized by a considerable thickness (more than 1500 m) of Lower Cretaceous, often monotonous grey to dark grey, prevailingly pelitic deposits. The biostratigraphy of the Upper Jurassic and Cretaceous sequence of strata is complicated. Occurences of ammonites, which are important as they are the fossil group defining the Cretaceous stages and substages, are rare in sediments of Hradiště Formation and absent in Vendryne formation and Tesin Limestones (Menčík et al., 1983). From the macrofaunal evidence, ammonites are more frequent from the Barremian to the Aptian, but occur discontinuously in isolated levels. In the Late Jurassic and lowermost Cretaceous part of the sequences, tintinnids occur sporadically (Pícha et al., 2006). However, Upper Jurassic and primarily Lower Cretaceous deposits are often noncalcareous as well as poor in macrofauna and microfauna (calpionellids, foraminifera) (Menčík et al., 1983). Organic-rich grey claystones and marlstones with well preserved assemblages of palynomorphs (Skupien, 1997, 1999, 2003, 2004, and others) present opportunities for a more extensive palynological study of the stratigraphy of these sediments. This study forms part of a project which aims to estimate the stratigraphic range of the Lower Cretaceous sediments.

The studied section is situated in the Moravskoslezské Beskydy Mountains, which belong to the Godula subunit of the Silesian unit (Fig. 1A); the Lower Cretaceous strata under study comprise the Vendryne Formation, the Tesin Limestone, and the Hradiste Formation.

Vašíček (1972a, b), based on sporadic macrofauna, assigned the Vendryne Formation to the Oxfordian to Tithonian age. The presence of the *Calpionella alpina* allocates the Tesin Limestone to the uppermost Tithonian to the Early Berriasian (Hanzlíková and Roth, 1964). The Hradiste Formation has been famous for a relative abundance of ammonites in the Barremian and Aptian (Vašíček, 1972a, and others).

The initial aim of the present study is to describe and illustrate the dinoflagellate cyst and acritarch assemblages recovered from the Lower Cretaceous sediments of the Silesian unit with particular emphasis on the biostratigraphical value to interpret or reinterpret the stratigraphic range of the formations. The quantitative compositions of palynomorphs and dinoflagellate cyst assemblages are used for palaeoenvironmental interpretation to revise previous interpretations and to understand the change from grey clays sedimentation to dark grey clays. The palynological data are correlated with a stable isotope stratigraphy of the Valanginian to Lower Hauterivian part of the section where grey claystones pass to dark grey claystones. The next aim is to determine whether the widespread Late Valanginian positive carbon isotope event (Lini et al., 1992) was represented there.

Figure 1 near here
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2. Geological setting

The Outer Western Carpathians represent the most external zone of the Western Carpathian mountain chain. In its present form, the Outer Carpathians consist of the Outer Group of Nappes divided from the lowest to the highest into the Subsilesian, Silesian, and Fore-Magura units and the Magura Group of Nappes divided into the Raca, Bile Karpaty, and Bystrica units (Fig. 1A). The whole nappe allochthon is thrust more than 60 km over the Miocene sediments of the Carpathian Foredeep (Pícha et al., 2006).

During the Mesozoic, the Outer Western Carpathians domain rimmed the southeast margin of the North-European Platform. This domain was separated by the Penninic Oceanic Branch from the Central Carpathian – Alpine microcontinent, associated with the Adriatic microcontinental assemblage since the Cimmerian collision. The Penninic rifting resulted in tensional stress, accelerating both the subsidence and tilting of Outer Carpathian intraplatform basins, accompanied by local volcanism (Mišík, 1992; Michalík, 1994).

Late Jurassic tectonic activity enhanced deposition in several troughs (from south to north the Magura, Silesian, and Subsilesian basins) separated by ridges. During the Early Cretaceous black shales with local submarine clastic fans embraced almost all Outer Carpathian basins. Slow and uniform sedimentation of green and black pelitic deposits took place during the Albian and Cenomanian. Red and variegated shales of the well-oxygenated conditions follow in the Upper Cretaceous. Locally more than 6 km thick flysch deposits are typical of the Outer Carpathian sedimentary sequences.

The Silesian unit is a part of the flysch zone of the Outer Western Carpathians representing the complex of allochthonous nappes. Three fundamentally different subunits (facies) are preserved in the present-day structure of the Silesian unit (Pícha et al., 2006), that is, the Godula subunit (basinal setting), the Baska subunit (frontal slope setting), and the Kelc subunit (continental slope setting).

The Skalice section enabled the palynological study of the lowermost part (latest Tithonian – Hauterivian) of the sequence of strata in the Godula subunit of the Silesian unit.

3. Material

The Skalice section is exposed in a series of outcrops totalling 156 m (Fig. 2), occurring in a channel, but above all on the left bank of the river Moravka, 1200 m NNE of the Straznice hill (altitude of 438 m) and about 500 m SE of the Vrchy hill (altitude of 435 m) at the eastern edge of the municipality of the village of Skalice (Fig. 1B). The mentioned section was described in detail by Skupien (2003). The position of samples taken follows from the geological column in Figure 2.

A higher part of the pelitic Vendryne Formation (Eliáš et al., 2003) was found. Vendryne Formation consists of brown-grey calcareous claystones. After interruption of the outcrop, due to cover by river sediments, the Tesin Limestone appears. Tesin Limestone exposed in the studied section consists of thin bedded grey limestones (mainly up to 5 cm, occasionally up to 40 cm), which are interbedded by grey to dark grey mainly calcareous claystones and siltstones. The limestones are prevailingly sandy and have the intrabiosparitic structure. As far as organic remains are concerned, sponge spicules, bryozoans, echinoid spines, radiolarians, benthic foraminifers (*Dorothia oxycona*, *Dorothia* sp., *Lenticulina* sp.), and fragments of shells of bivalves and brachiopods are present (Skupien, 2003). Higher Tesin Limestone gradually passes into dark pelitic sediments of the lower part of the Hradiste Formation. Grey to dark grey calcareous and noncalcareous claystones prevail. Thin bedded fine grained sandstones occur within this lithostratigraphic unit.

Figure 2 near here

Fifty-four samples of grey claystones were studied palynologically (Figs. 2, 5). Twenty-eight samples of dark grey claystones were collected for the total organic carbon (TOC) content (Tab. 1). Twenty-two bulk samples from the Valanginian and Early Hauterivian part of the section were selected for $\delta^{13}C$ stratigraphy.

Table 1 near here
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4. Methods

A total of 54 rock samples, mostly recovered from the dark claystone beds, were processed by a standard palynological technique, that is, by dissolution in HCl and HF with subsequent sieving on polyethylene sieves with a mesh size of 15 μm. The palynological permanent mounts are stored at the Institute of Geological Engineering at the VSB – Technical University of Ostrava, Czech Republic. For suitable samples, qualitative observation was supplemented by quantitative analysis.

The quantitative study includes two steps:

I. Counting of the whole assemblage of up to 150 palynomorphs; this step includes the recognition of five broad palynomorph categories (Fig. 3): dinoflagellate cysts, foraminiferal linings (inner walls of foraminifers), acritarchs, bisaccate pollen, and other pollen and spores (sporomorphs excluding bisaccates).

II. Counting of up to 250 determinable dinoflagellate cysts when possible. Dinoflagellate cysts were grouped into six palaeoenvironmentally significant groups (Fig. 4, modified after Wilpshaar and Leereveld, 1994; Leereveld, 1995):

1. Varying salinity group (restricted shallow marine). The regular dominance of the group may be the result of freshwater influx and nutrient supply (Leereveld, 1995). Freshwater and nutrient influx implies increased runoff, possibly resulting from increased precipitation. This group comprises representatives of the genera *Muderongia*, *Odontochitina*, *Phoberocysta*, and *Subtilisphaera*.
2. Littoral group (*Canningia, Circulodinium, Pseudoceratium, Systematophora*).
3. Inner neritic group (*Cribroperidinium, Apteodinium*).
4. Neritic I group (*Achomosphaera*, *Spiniferites*, and morphologically closely related taxa).
5. Neritic II group (*Florentinia*, *Kleithriasphaeridium*, *Oligosphaeridium*).
6. Oceanic group (*Hapsocysta*, *Pterodinium*). The oceanic group is the only autochthonous group (not transported from the shelf, but living in the oligotrophic pelagic water) in the turbiditic type of sediments.

Figures 3 and 4 near here

Four methods were used to interpret palynological assemblage fluctuations in terms of environmental changes: a) the ratio of marine palynomorphs (acritarchs, dinoflagellate cysts, foraminiferal linings) to land-derived palynomorphs (pollen and spores); b) changes in relative abundance of palaeoenvironmental dinocyst groups; c) dominance ratio expressed as the number of specimens of the most abundant genus plus the number of specimens of the second most frequent genus to the total number of determinable dinoflagellate cysts; d) diversity expressed as the number of genera found in each sample. Warm-water and cold-water species were recognized according to Leereveld (1995).

Total organic carbon content (TOC) of the whole rock was defined from the CO_2 gas volume measured with a EuroEA 3000 equipment.

Analysis of stable isotopes was undertaken by the Czech Geological Survey in Prague. Rock-chips with diagenetic calcite veinlets were removed under a binocular microscope. Bulk rock samples for isotopic analysis were drilled with a dentists drill from a clean rock surface, usually a cut plane. Marly samples, which were too soft to drill, were ground with an agate mortar. Sample material was reacted with 100% phosphoritic acid and the carbon and oxygen isotope composition of the evolving CO_2 gas was analysed with a Finigan MAT-2 spectrometer in Prague. Analyses were done using standard techniques. Instrumental drift was corrected with the use of the NBS standard. The isotopic data are reported in the usual ‰ notation relative to the International Isotopic Standard VPDB (Vienna Pee Dee Belemnite).

5. Results

Out of the 54 samples prepared for palynomorphs, 45 proved to be fossiliferous. In general, samples give rich, diverse, well-preserved palynological assemblages. Marine elements predominate in all of them, being represented mainly by dinoflagellate cysts, some acritarchs, and foraminiferal linings (Fig. 3). Terrestrial elements are subordinate in quantity and are represented by the spores and pollen grains.

The stratigraphical distributions of 86 dinoflagellate cysts and acritarchs taxa encountered in the Skalice section are shown in the range chart of Fig. 5. Unidentifiable dinoflagellate cysts were not counted, but constitute <15% of the overall assemblages. Reworked specimens of dinoflagellate cysts constitute a minor percentage of the examined material and are included in the counting. In general, they were identified not by their different state of preservation but by their known stratigraphical ranges.

Assemblages are composed mainly of ceratioid taxa *Muderongia* and *Pseudoceratium*. The lower part of the section with Tesin Limestone is characterized by relatively frequent chorate taxa like *Kleithriasphaeridium* (*K. fasciatum, K. eoinodes*) and *Systematophora* (*S. areolata, S. penicillata, S. scoriacea*, *Systematophora* sp. A). Representatives of the genus *Circulodinium* are abundant in the Hradiste Formation. The stratigraphical occurrences (first or last occurrences) of diagnostic taxa, recorded in the Skalice section, are shown in Fig. 2.

Organic carbon (TOC) reached 0.65 to 5.76 wt.% values in the section studied (Tab. 1). Microscopic investigation of palynofacies of claystones revealed two principal types of organic matter (marine and terrestrial), differently preserved (oxidized) and diagenetically transformed. The oxidization grade in Tesin Limestone is high. A low oxidization grade is documented by the presence of dinoflagellate cysts and brown wood in the Hradiste Formation. An enhanced influx of nutrients into the marine environment during prograding transgression stimulated high algal productivity and the terrestrially derived organic material caused an additional oxygen decrease which promoted anoxia in the Late Valanginian and Early Hauterivian age.

The C and O isotopic composition of the Valanginian and Early Hauterivian part of the Hradiste Formation has been studied in 21 bulk samples (Fig. 2, Tab. 1). The results indicated a perturbation of the carbon cycle during the Late Valanginian. The values of $\delta^{13}C$ increased significantly from a level of 0.43‰ to 1.81‰. The $\delta^{18}O$ ratio of claystones changes from –4.31 to –5.91‰.

6. List of encountered taxa

An alphabetic index of dinocyst taxa is provided below. Taxonomic citations can be found in Fensome and Williams (2004). Numbers in parentheses refer to the position of the species in the distribution chart of the Skalice section (Fig. 5). Selected dinoflagellate cysts are illustrated in Figs. 6 and 7.

Achomosphaera neptuni (Eisenack, 1958a) Davey and Williams, 1966a (38)

Amphorula delicata van Helden, 1986 (35)

Amphorula metaelliptica Dodekova, 1969 (10)

Aprobolocysta galeata Backhouse, 1987 (59)

Bourkidinium granulatum Morgan, 1975 (43)

Bourkidinium sp. 1 Leereveld, 1997 (21)

Callaiosphaeridium asymmetricum (Deflandre and Courteville, 1939) Davey and Williams, 1966b (79)

Cauca parva (Alberti, 1961) Davey and Verdier, 1971 (77)

Chlamydophorella nyei Cookson and Eisenack, 1958 (49)

Circulodinium distinctum (Deflandre and Cookson, 1955) Jansonius, 1986 (27)

Circulodinium vermiculatum Stover and Helby, 1987c (72)

Cometodinium habibii Monteil, 1991a (24)

Cometodinium multispinosum (Singh, 1964) Masure in Fauconier and Masure, 2004 (32)

Cribroperidinium confossum (Duxbury, 1977) Helenes, 1984 (83)

Cribroperidinium? *longicorne* (Downie, 1957) Lentin and Williams, 1985 (2)

Cribroperidinium spp. (14)

Ctenidodinium elegantulum Millioud, 1969 (19)

Cyclonephelium intonsum Duxbury, 1983 (33)

Cyclonephelium spp. (25)

Cymososphaeridium validum Davey, 1982b (73)

Cymososphaeridium cf. *validum* Davey, 1982b (48)

Dapsilidinium multispinosum (Davey, 1974) Bujak et al., 1980 (75)

Dapsilidinium warrenii (Habib, 1976) Lentin and Williams, 1981 (39)

Dichadogonyaulax bensonii Monteil, 1992a (45)

Dingodinium cerviculum Cookson and Eisenack, 1958 (74)

Dissiliodinium globulus Drugg, 1978 (65)

Exochosphaeridium muelleri Yun, 1981 (62)

Gonyaulacysta spp. (9)

Heslertonia heslertonensis (Neale and Sarjeant, 1962) Sarjeant, 1966b (41)

Hystrichodinium pulchrum Deflandre, 1935 (28)

Hystrichodinium voigtii Alberti, 1961 (46)

Hystrichosphaerina schindewolfii Alberti, 1961 (55)

Impletosphaeridium ehrenbergii (Deflandre, 1947c) Islam, 1993 (1)

Kleithriasphaeridium corrugatum Davey, 1974 (64)

Kleithriasphaeridium eoinodes (Eisenac, 1958a) Davey, 1974 (51)

Kleithriasphaeridium fasciatum Davey and Williams, 1966b (22)

Kleithriasphaeridium suevicum Dürr, 1988 (3)

Muderongia longicorna Monteil, 1991b (17)

Muderongia mcwhaei form A Cookson and Eisenack, 1958, emend. Monteil, 1991b (67)

Muderongia mcwhaei form B Cookson and Eisenack, 1958, emend. Monteil, 1991b (76)

Muderongia simplex subsp. *microperforata* Davey, 1982b (61)

Muderongia pariata Duxbury, 1983 (70)

Muderongia simplex Alberti, 1961 (57)

Muderongia staurota Sarjeant, 1966c (84)

Muderongia spp. (12)

Occisucysta duxburyi Jan du Chêne et al., 1986b (52)

Occisucysta tentorium Duxbury, 1977 (58)

Oligosphaeridium albertense (Pocock, 1962) Davey and Williams, 1969 (85)

Oligosphaeridium? *asterigerum* (Gocht, 1959) Davey and Williams, 1969 (81)

Oligosphaeridium complex (White, 1842) Davey and Williams, 1966b (66)

Oligosphaeridium diluculum Davey, 1982b (34)

Oligosphaeridium dividuum Williams, 1978 (86)

Oligosphaeridium poculum Jain, 1977b (82)

Oligosphaeridium pulcherrimum (Deflandre and Cookson, 1955) Davey and Williams, 1966b (29)

Ovoidinium diversum Davey, 1979b (60)

Phoberocysta neocomica (Gocht, 1957) Millioud, 1992 (26)

Phoberocysta tabulata Raynaud, 1978 (31)

Prolixosphaeridium granulosum (Deflandre, 1937b) Davey et al., 1966 (63)

Prolixosphaeridium cf. *granulosum* (Deflandre, 1937b) Davey et al., 1966 (15)

Prolixosphaeridium cf. *parvispinum* (Deflandre, 1937b) Davey et al., 1969 (80)

Prolixosphaeridium sp. A Monteil, 1993 (16)

Protoellipsodinium spinosum Davey and Verdier, 1971 (68)

Pseudoceratium gochtii Neale and Sarjeant, 1962 (56)

Pseudoceratium pelliferum Gocht, 1957 (47)

Scriniodinium campanula Gocht, 1959 (13)

Sentusidinium spp. (6)

Stanfordella cretacea (Neale and Sarjeant, 1962) Helenes and Lucas-Clark, 1997 (37)

Stiphrosphaeridium dictyophorum (Cookson and Eisenack, 1958) Lentin and Williams, 1985 (7)

Stiphrosphaeridium cf. *„sarjeantii“* (Gitmez, 1970) Courtinat, 1989 (8)

Systematophora areolata Klement, 1960 (23)

Systematophora complicata (Neale and Sarjeant, 1962) Eisenack, 1969a (40)

Systematophora palmula Davey, 1982b (53)

Systematophora penicillata (Ehrenberg, 1843) Sarjeant, 1980a (4)

Systematophora scoriacea (Raynaud, 1978) Monteil, 1992b (5)

Systematophora silybum Davey, 1979a (54)

Systematophora sp. A Monteil, 1993 (20)

Systematophora spp. (44)

Tanyosphaeridium isocalamum (Deflandre and Cookson, 1955) Davey and Williams, 1969 (42)

Tanyosphaeridium sp. DE Brideaux, 1977 (69)

Tanyosphaeridium spp. (18)

Tehamadinium evittii (Dodekova, 1969) Jan du Chêne et al., 1986b (50)

Tubotuberella apatela (Cookson and Eisenack, 1960b) Ioannides et al., 1977 (11)

Wallodinium cylindricum (Habib, 1970) Duxbury, 1983 (36)

Wallodinium krutzschii (Alberti, 1961) Habib, 1972 (30)

Wallodinium luna (Cookson and Eisenack, 1960a) Lentin and Williams, 1973 (78)

Wrevittia helicoidea (Eisenack and Cookson, 1960) Helenes and Lucas-Clark, 1997 (71)

7. Discussion

7.1. Dinoflagellate biostratigraphy

The stratigraphic assignment of the studied sediments according to dinoflagellate cysts is characterized below (Figs. 2, 5). To determine the age of the strata based on the distribution of dinoflagellate cysts, species ranges were compared with other studies in the Northern

Hemisphere (Jan du Chêne et al., 1986; Leereveld, 1995, 1997; Monteil, 1992, 1993; Stover, 1996).

The lower part of the section (Vendryne Formation) represents the Upper Tithonian, as indicated by the presence of *Amphorula metaelliptica, Cribroperidinium*? *longicorne, Gonyaulacysta* sp., *Sentusidinium* sp., *Stiphrosphaeridium dictyophorum*, *S.* cf. *sarjeantii*, *Systematophora penicillata, S. scoriacea*, and *Tubotuberella apatela* (Monteil, 1992; Stover, 1996). *Scriniodinium campanula* was found in sample SKb18. Representatives of the genus *S. campanula* have their first occurrence in the beginning of the Berriasian (Figs. 2, 5).

Figure 5 near here

The assemblage of dinoflagellate cysts of the lower part of the Tesin Limestone (sample interval SKb17–SKb12) with the species *Circulodinium distinctum, Cometodinium habibii, Kleithriasphaeridium fasciatum, Muderongia longicorna, Phoberocysta tabulata, Prolixosphaeridium* sp. A, *Systematophora areolata*, *S. penicillata, S. scoriacea*, and *Systematophora* sp. A. is characteristic for Late Berriasian age. *Kleithriasphaeridium fasciatum* has its first occurrence in the uppermost Berriasian (Otopeta Ammonite Subzone; Monteil, 1992, 1993).

Stanfordella cretacea appears in sample SKb10. The previous first occurrence of this species is considered by Leereveld (1997) to be from the Early Valanginian. Other species of dinoflagellate cysts whose first occurrences are stated by both Monteil (1992, 1993) and Leereveld (1997) to be on the Berriasian/Valanginian boundary are missing from the section.

A stratigraphically important assemblage with *Hystrichosphaerina schindewolfii, Kleithriasphaeridium eoinodes, Occisucysta duxburyi, Systematophora palmula, S. silybum,* and *Tehamadinium evitii* firstly occurs from the level of the sample SKb6 (Figs. 2, 5). The first three of these species are known from the Early Valanginian, namely its higher part, that is, the Campylotoxus Ammonite Zone (Jan du Chêne et al., 1986; Leereveld, 1997). *Oligosphaeridium complex* (the first occurrence in sample SKb5) also indicates the Early Valanginian (Leereveld, 1995, 1997). The last occurrences (sample SKb2 of the Skalice section) of *Kleithriasphaeridium fasciatum, Prolixosphaeridiuim* sp. A, *Systematophora areolata*, and *S. scoriacea* are Early Valanginian (Monteil, 1992). In the sample SK4 *Muderongia mcwhaei* (form A; Monteil, 1991) appears firstly; it has, according to Monteil (1992), a stratigraphic range from the Late Berriasian to the Early Valanginian. However, in the Skalice section *Muderongia mcwhaei* (form A) is most abundant in the upper part of the section (samples SK29 and SK30), which, according to the dinoflagellate cysts, belongs to the Late Valanginian.

In summary, interpretation of the data suggests that the part of the section including the samples SKb10–SKb1 and SK1–SK7 is Early Valanginian in age (probably the higher part of the Pertransiens Ammonite Zone and the Campylotoxus Ammonite Zone).

Cymososphaeridium validum appears in sample SK9. Its first occurrence is known from the Late Valanginian (from the Verrucosum Ammonite Zone, Leereveld, 1995, 1997).

From stratigraphically important dinoflagellate cyst species, *Dingodinium cerviculum* and *Dapsilidinium multispinosum* appear in the sample SK10 and *Muderongia mcwhaei* (form B; Monteil, 1991) appear in the sample SK11. They are characteristic of a Valanginian age.

Muderongia staurota was identified in the sample SK30. *M. staurota* has its first occurrence from the Hauterivian (Leereveld, 1995, 1997). This sample can also be regarded as the horizon of the last occurrence of the species *Bourkidinium granulatum, Circulodinium vermiculatum, Dissiliodinium globulus, Muderongia longicorna, M. simplex, Occisucysta duxburyi, Phoberocysta neocomica*, and *Systematophora palmula*.

7.2. Quantitative study

A palynological study of the section was carried out in order to investigate palynomorph and dinoflagellate cyst fluctuations (Figs. 3, 4).

The palynomorph assemblage of the Vendryne Formation contains a high content of very poorly preserved dinoflagellate cysts. Together with them, the inner linings of foraminifers and bisaccate pollen grains are present. This composition shows the conditions of open sea with the limited supply of terrestrial material (Stover et al., 1996).

Dinoflagellate cysts are dominant in the samples taken from the lower part of Tesin Limestone too. The increase in relative abundance of bisaccate pollen grains and other sporomorphs in the Early Valanginian indicates an increased supply of terrestrial material. The composition of sediments, in which the number of layers of sandy limestones to calcareous sandstones increases, corresponds as well. Acritarchs (especially the species *Wallodinium cylindricum* and *W. krutzschii*) and the inner linings of foraminifers occur in negligible amounts.

In the composition of dinoflagellate cyst assemblages of the Tesin Limestone, the littoral group prevails, mainly the species *Circulodinium distinctum*, *Pseudoceratium pelliferum*, *Systematophora areolata*, *S. palmula*, *S. scoriacea*, and *S. silybum*. An increase in the proportion of this group of dinoflagellate cysts is connected with a decrease in the abundance of dinoflagellate cysts belonging to the group of varying salinity (*Muderongia*). This palynofacies characterizes a relatively shallow marine environment with a mixture of nearshore dinocysts with eutrophic and less saline surface waters (Leereveld, 1995). Both the groups were redeposited into the deeper parts of the sedimentary basin. This fact is also supported by the occurrence of the genera *Kleithriasphaeridium* and *Oligosphaeridium* (neritic group II), which are characteristic of the conditions of open sea and may be taken as autochthonous (Leereveld, 1995). Besides the abovementioned palaeoecological groups of dinocysts, the species *Cometodinium habibii* is abundant in the assemblage of the lowermost and upper parts of the Tesin Limestone. What is very interesting is the dominance of the species *Cometodinium habibii*, which forms up to 40% of the dinocyst assemblage in the samples SK4, SK5, and SK6.

The Late Valanginian palynomorph assemblage of the Hradiste Formation is characterized by an increase in the content of sporomorphs with the maximum in the sample SK20. High amount of terrestrial organic matter points at intense supply of land-derived organic particles or shallowing of conditions. An increased supply of continental material probably reflects higher precipitation on land, resulting in enhanced nutrient supply to coastal waters and enhanced organic particle transport to the shelf margin. A small amount of inner linings of foraminifers and very sporadically acritarchs (species *Wallodinium krutzschii*) appear in this interval.

In the assemblages of dinoflagellate cysts, the proportion of representatives of the varying salinity group (above all *Muderongia*) increases and simultaneously the proportion of the littoral group decreases. These, probably reworked dinoflagellate cysts, characteristic of a near-shore environment are accompanied by the presence of a small amount of dinoflagellate cysts typical of the environment of open sea, that is, the neritic group I and the neritic group II (Wilpshaar and Leereveld, 1994; Leereveld, 1995).

A palynofacies of the higher part of the section with prevailing dark pelites (samples SK15–SK35) is characterized by poorly preserved dinocysts. Therefore this part of the section cannot be evaluated quantitatively in detail. The composition of assemblages of dinoflagellate cysts can only be evaluated in the samples SK16, SK20, SK21, SK22, SK29, and SK30.

The assemblages of dinoflagellate cysts of all five samples are again characterized by the dominance of near-shore, shallow-sea dinoflagellate cysts, namely of the varying salinity group (e.g. *Muderongia*) and the littoral group (e.g. *Circulodinium*, *Pseudoceratium*). With reference to the presence of neritic species (above all *Achomosphaera, Kleithriasphaeridium,* *Oligosphaeridium*), the redeposition of both groups of dinoflagellate cysts from the littoral zone to the area of open sea can be supposed.

Dinoflagellate cyst assemblages in the Skalice section comprise almost entirely warm-water Tethyan species. The species *Hystrichosphaerina schindewolfii, Stiphrosphaeridium dictyophorum,* and *Tubotuberella apatela,* which are regarded as boreal elements (e.g. Leereveld, 1995; Monteil, 1993), occur rarely in the uppermost part of the Vendryne Formation of the Late Tithonian age, in the Tesin Limestone of the Early Valanginian age, and in the Hradiste Formation of the Late Valanginian age. The presence of these species may indicate a rather cool sea surface or communication with the boreal bioprovince probably through the Danish-Polish Trough in the Valanginian and the Early Hauterivian (Vašíček and Michalík, 2002).

7.3. Isotope record

The results of C and O isotope analyses of the Valanginian bulk samples of the upper part of the Tesin Limestone and from the Hradiste Formation are presented in Fig. 2 and Tab. 1. The C-isotopic profile shows increased $\delta^{13}C$ values to 1.81‰ and the characteristically documented global change in the C-cycle. Acccording to dinoflagellates, the change corresponds with the Upper Valanginian. It can be assumed to be around the boundary of the Verrucosum and Peregrinus ammonite zones. The $\delta^{13}C$ change correlates with the terrestrial/marine organic matter ratio, which increased in the samples interval SK16–SK20. The $\delta^{13}C$ maximum was recorded in a black shale layer with low TOC, strongly oxidized terrestrial organic matter, and pyrite. Noticeably, decreased values of $\delta^{18}O$ in a part of the rock column studied could be connected with a temperature decrease and/or with intensified freshwater input into the ocean which is identified by increased terrestrial palynomorphs input.

A similar change of the $\delta^{13}C$ values was documented in the Late Valanginian of the Pieniny Klippen Belt of the Western Carpathians (Michalík et al., 1995), Jura platform, Helvetics, Vocontian basin, Alps (Lini et al., 1992, Fischer, 2003). The Valanginian isotopic excursion has been typically recorded from carbonates (e.g Lini et al., 1992, etc.) but also terrestrial organic matter from the Crimea (Gröcke et al., 2005). This event differs from Aptian-Albian and Cenomanian-Turonian events by the absence of large-scale marine source rock deposition.

8. Conclusions

In the identified assemblages of dinoflagellate cysts, stratigraphically significant species have been found, enabling the stratigraphic assignation of sediments of individual lithostratigraphic units in the locality of Skalice. On the basis of quantitative composition, it was also possible to characterize a change in the palaeoenvironment from the Berriasian to the Hauterivian.

In summary, interpretation of our data suggests that sedimentation of the upper part of the Vendryne Formation in the studied part of the Silesian basin is Early Berriasian in age. This is in contradiction with the Oxfordian to Tithonian age suggested by Vasicek (1972a, b).

The age of the Tesin Limestone was previously interpreted as uppermost Tithonian to Early Berriasian (Hanzlikova and Roth, 1964). We proposed herein Early Valanginian or possibly basal Late Valanginian age for the final sedimentation of the Tesin Limestone. Pelitic flysch-like sediments of the Hradiste Formation belong to the Late Valanginian up to the Early Hauterivian.

In the palynospectra of the whole studied part of the locality of Skalice, dinoflagellate cysts prevail. This corresponds to the conditions of open sea. Towards the overlying layers, an increase in the proportion of sporomorphs can be observed. They are the most abundant in the palynospectra of the Hradiste Formation in the latest Valanginian and the Early Hauterivian.

They indicate an increased supply of terrestrial material. The assemblages of dinoflagellate cysts are characterized by their origin in the conditions of shallow sea with variable salinity. It is probably a case of redeposition of these species in the area of deeper shelf (a small amount of dinocysts characteristic of the environment of open sea are present).

In addition to the prevailing Tethyan species, in the whole part from the Late Tithonian to the Early Hauterivian, dinoflagellate cysts stated as boreal elements are present in some samples. Those indicate possible periodical communication between the Silesian sedimentary basin and the boreal bioprovince especially in the Valanginian and/or the cooling of sea surface.

The increased $\delta^{13}C$ value in the Late Valanginian can be correlated with that from other sections of the Tethyan realm. The change in the isotopic ($\delta^{13}C$ and $\delta^{18}O$) record could be connected with a temperature decrease and/or with an intensified freshwater input into the ocean (increase of terrestrial palynomorphs input) in the Late Valanginian. The increase of organic matter storage is connected with the dark grey clays sedimentation.

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Figures 6 and 7 near here

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Figure 1A – Tectonic map of the Outer Western Carpathian area in the eastern part of the Czech Republic (its position in the frame of middle Europe is indicated in the upper left corner). B – Location map of the Skalice section. Section is indicated with thick line. Sample position SKb21 marks beginning of the section. Sample position SK35 marks termination of the section.

Figure 2. Geological column showing lithology of the Skalice section (151 m thick) with lithostratigraphy and biostratigraphy. Stratigraphy is determined based on dinoflagellate cysts (this work). On the right, levels of the analysed samples and the first and last occurrences of key dinoflagellate cysts are indicated. Content of TOC and $\delta^{13}C$ and $\delta^{18}O$ isotope curves in selected samples from Hradiste Formation are displayed in the upper part of the section.

Figure 3. Relative abundance of palynomorphs in the Skalice section. Data are based on counts of up to 150 palynomorphs.

Figure 4. Relative abundance of dinoflagellate cyst palaeoenvironmental groups in the Skalice section. Data are based on counts of up to 250 specimens. Dinoflagellate cysts were grouped into six palaeoenvironmentally significant groups (modified after Wilpshaar and Leereveld, 1994; Leereveld, 1995).

Figure 5. Distribution of acritarchs and dinoflagellates in the Skalice section. Numbers of specimens recorded are based on counts of up to 250 specimens. Samples missing with respect to progressive numbering proved to be barren or to yield undetermined palynomorphs. Vertical scale not proportional to stratigraphic thicknesses.

Table 1. Content of TOC, $\delta^{13}C$, and $\delta^{18}O$ in samples of the upper part of the Skalice section.

Figure 6

The species name is followed by the size of the specimens, preparation slide number, sample location and England Finder coordinates (for localization of the specimen on the slide).

A. *Systematophora areolata*; diameter 75 μm, SKb10, K39.

B. *Dapsilidinium warrenii*; body diameter 30 μm, SKb10, S42.

C. *Phoberocysta tabulata*; width 70 μm, SKb10, W38/2.

D. *Systematophora penicillata*; diameter 85 μm, SKb8, X42.

E. *Wallodinium cylindricum*; length 52 μm; SKb8, L 35.

F. *Pseudoceratium pelliferum*; length 120 μm, SKb6, K/L40.

G. *Cribroperidinium* spp; length 89 µm, SKb2, M40.

H. *Systematophora complicata*; diameter 69 µm; SKb2, J 12.

I. *Scriniodinium campanula*; length 67 µm, SKb2, T29/1.

J. *Oligosphaeridium pulcherrimum*; diameter 88 µm; SKb2, D 40/2.

K. *Occisucysta duxburyi*; width 52 µm, SKb1, L48.

L. *Systematophora palmula*; diameter 78 µm; SKb2, S/T32.

M. *Hystrichodinium pulchrum*; length 100 µm; SKb1, Z 31/2.

N. *Occisucysta tentorium*; width 58 µm; SKb1, Q 16/4.

O. *Kleithriasphaeridium corrugatum;* length 70 µm, SKb1, S35.

P. *Cymososphaeridium validum*; diameter 75 µm, SKb1, P42/43.

Q. *Prolixosphaeridium granulosum*; length 80 µm, SKb1, R35.

R. *Systematophora* sp.; diameter 87 µm, SK4, F41/2.

Figure 7

The species name is followed by the size of the specimens, preparation slide number, sample location and England Finder coordinates (for localization of the specimen on the slide).

A. *Hystrichosphaerina schindewolfii*; width 66 µm; SK4, N 46.

B. *Cometodinium habibii*; diameter 68 µm, SK4, P28.

C. *Cribroperidinium* sp.; length 95 µm, SK10, I38/2.

D. *Muderongia simplex*; width 83 µm, SK6, V 49.

E. *Muderongia simplex microperforata*; length 78 µm, SK10, G33/34.

F. *Stanfordella cretacea*; width 43 µm; SK6, T 28/2.

G. *Circulodinium vermiculatum*; width 80 µm, SK10, O47/2.

H. *Cymososphaeridium validum*; diameter 75 µm, SK10, P42/43.

I. *Oligosphaeridium complex*; inner body diameter 35 µm; SK12, J 22.

J. *Muderongia mcwhaei* form A; width 90 µm, SK12, V31.

K. *Bourkidinium granulatum*; length 52 µm, SK10, M42.

L. *Oligosphaeridium pulcherrimum*; diameter 90 µm; SK12, E/F42.

M. *Muderongia simplex*; width 93 µm, SK12, N48/49.

N. *Muderongia mcwhaei* form A; width 95 µm, SK30, S28/3.

O. *Circulodinium distinctum*; width 61 µm SK30, W57.

P. *Wallodinium krutzschii*; length 76 µm; SK12, J 36/1.

Q. *Systematophora silybum*; diameter 81 µm, SK32, K37/2.

Figure1

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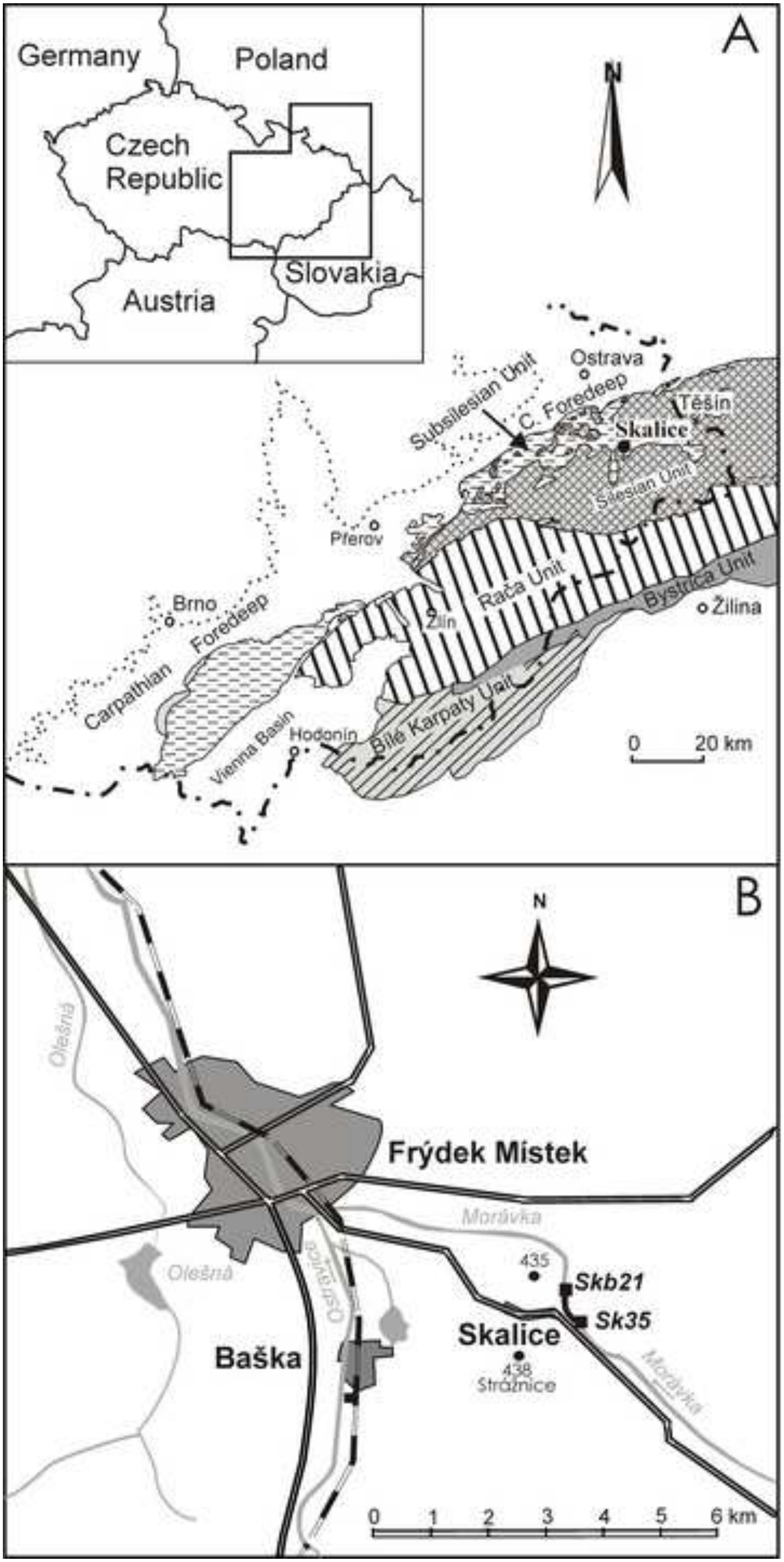

Figure2

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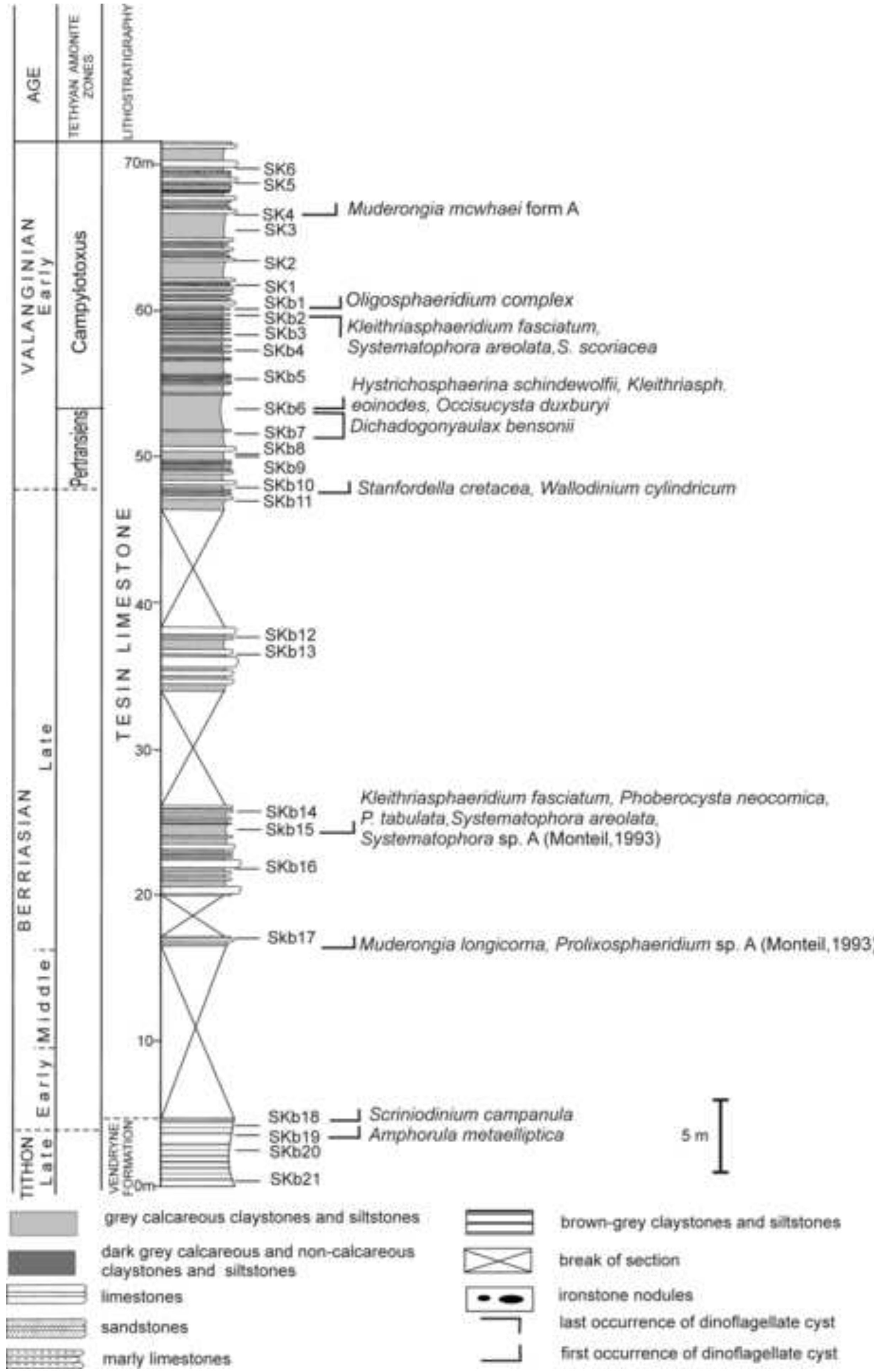

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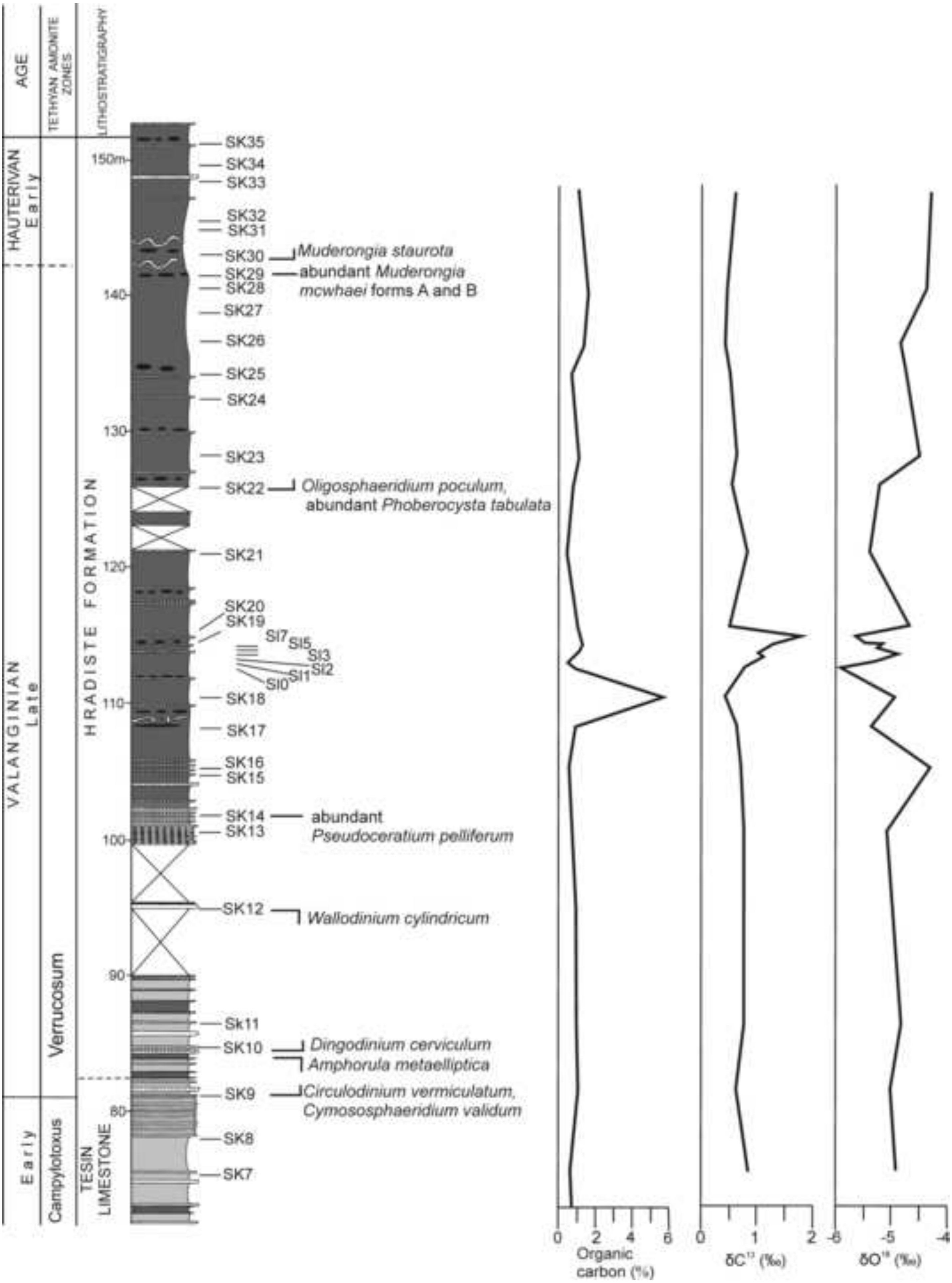

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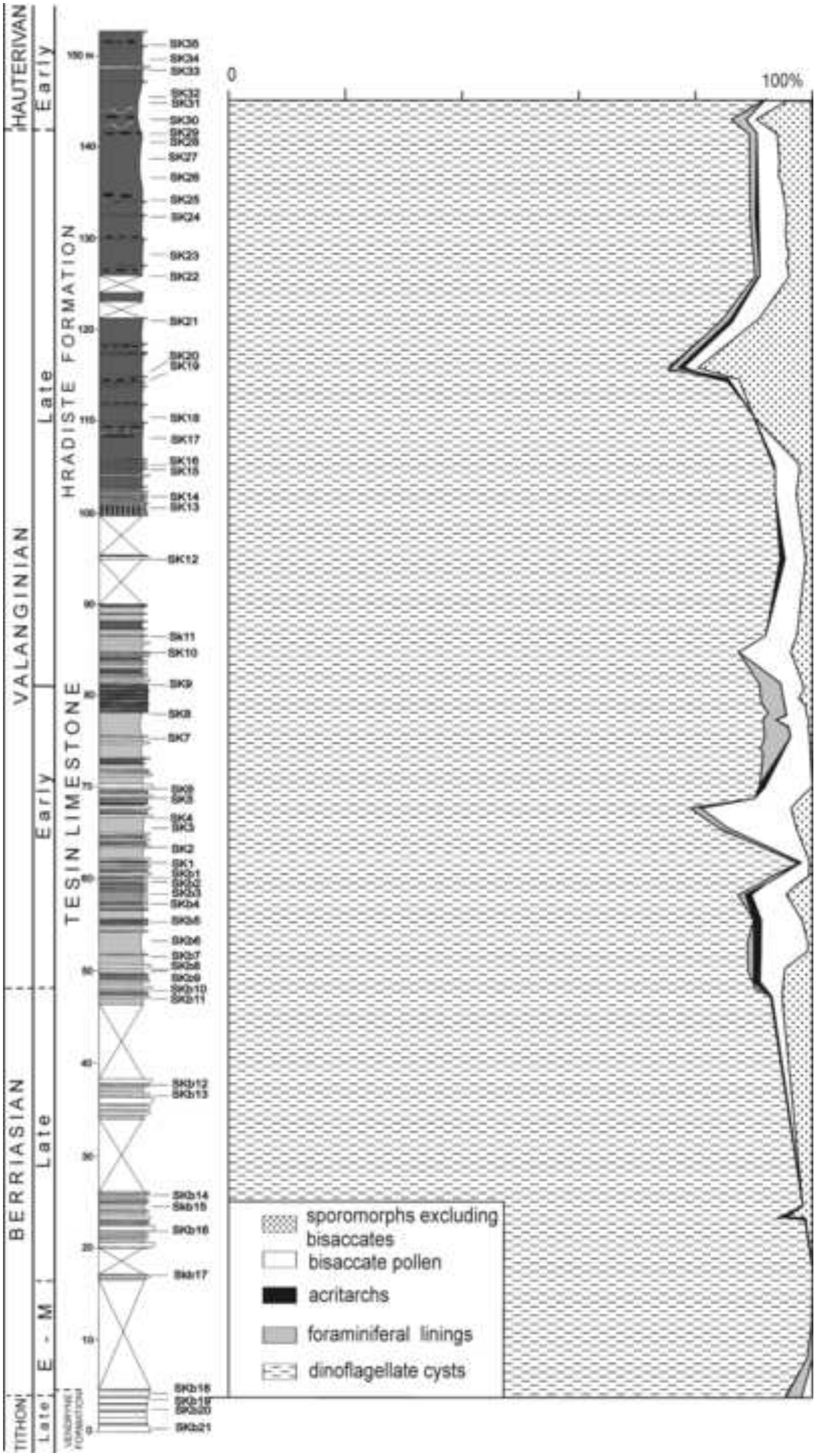

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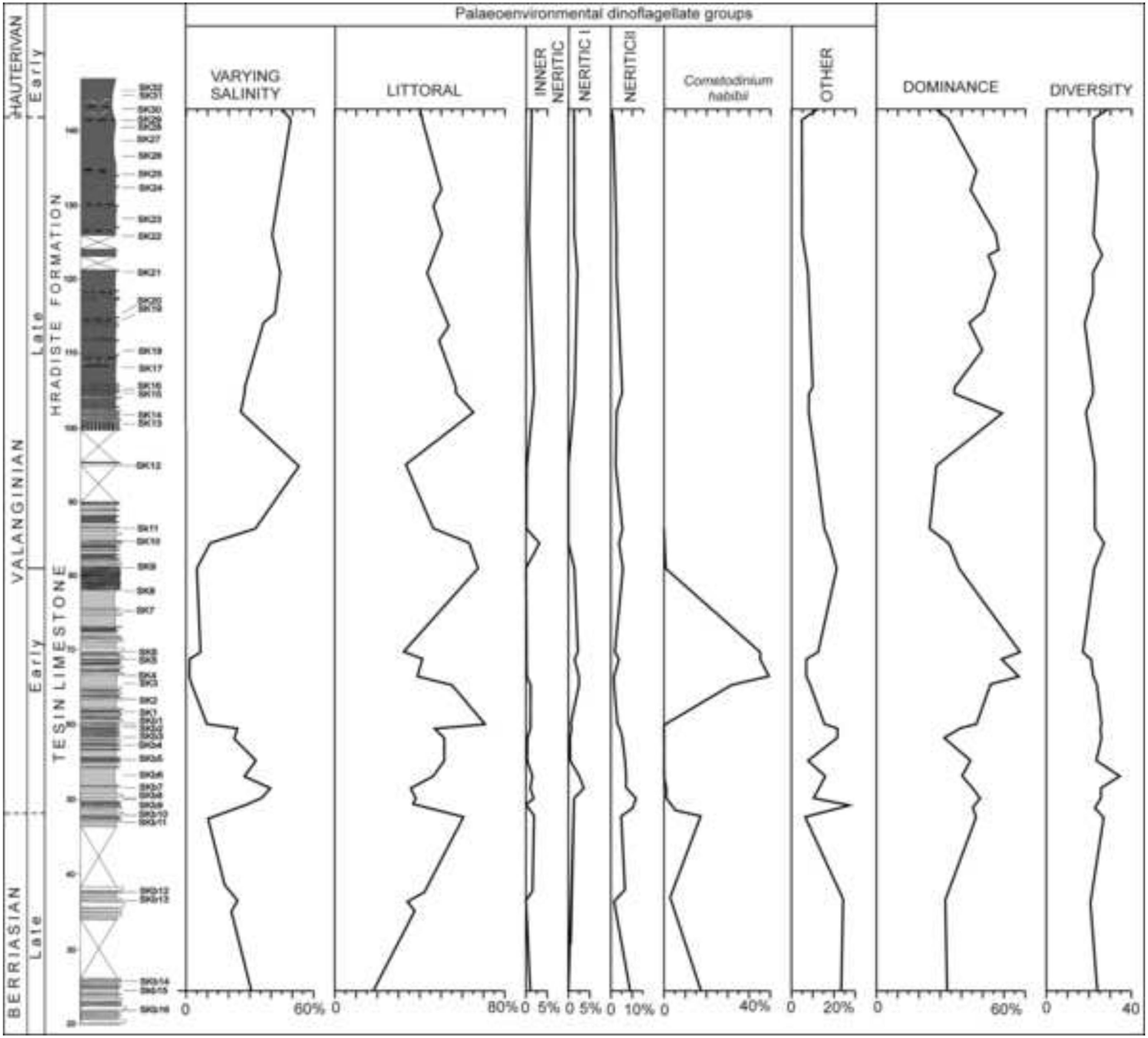

Figure5

AGE	TITHON		BERRIAS.					VALANGINIAN																																		HAUTERIV			
	Late		E.	Late				Early																	Late																	?			
LITHOSTRATIGRAPHY	Vendryne Fm			Tesín Limestone																						Hradiste Formation																			
SAMPLES / TAXA	SKb 20	SKb 19	SKb 18	SKb 17	SKb 15	SKb 13	SKb 12	SKb 10	SKb 9	SKb 8	SKb 7	SKb 6	SKb 5	SKb 4	SKb 3	SKb 2	SKb 1	SK 1	SK 2	SK 3	SK 4	SK 5	SK 6	SK 7	SK 9	SK 10	SK 11	SK 12	SK 14	SK 15	SK 16	SK 18	SK 19	SK 20	SK 21	SK 22	SK 24	SK 25	SK 26	SK 27	SK 29	SK 30	SK 32	SK 33	SK 34
1. *Impletosphaeridium ehrenbergii*	1	1																																											
2. *Cribroperidinium*? *longicorne*	1	2																																											
3. *Kleithriasphaeridium suevicum*	1	1																																											
4. *Systematophora penicillata*	3	5	1	2	10		2	1	2	6																																			
5. *Systematophora scoriacea*	4	5	1	3	12	1		15	11	8	12	18			2	4																													
6. *Sentusidinium* sp.		10																																											
7. *Stiphrosphaeridium dictyophorum*		1			1																																								
8. *Stiphrosphaeridium* cf. *sarjeantii*		11	1		2																																								
9. *Gonyaulacysta* sp.		3	1		4										2																														
10. *Amphorula metaelliptica*		2			1			1		5	3	2	3	1	3	4										1																			
11. *Tubotuberella apatela*		2							3	4	3	2			1		1									1			1																
12. *Muderongia* sp.		1																					6	8	4			33						5							10	37			
13. *Scriniodinium campanula*			1		7			4	6	2	5	6	2		1	5				2	3	2	1		4	3		8					1	2	1						2	2	1	2	
14. *Cribroperidinium* sp.			1		2			6		6	2	2				2	3			1	1			4		8			2	3	4			1		4					2	4	1	1	3
15. *Prolixosphaeridium* cf. *granulosum*				1																																									
16. *Prolixosphaeridium* sp. A				18	4		1	1								1																													
17. *Muderongia longicorna*				25	32	3	5		14				2		7	1											18	40	1	2	2	5	2	8	9	11					1	1			
18. *Tanyosphaeridium* spp.					1																																								
19. *Ctenidodinium elegantulum*					1			1	2	3																																			
20. *Systematophora* sp. A					13	2	1	10	4	7	2	1																																	
21. *Bourkidinium* sp. 1					1				1		3	7			1																														
22. *Kleithriasphaeridium fasciatum*					17		4	8	9	21	14	10	8	1	5	5																													
23. *Systematophora areolata*					16	6		84	62	14	21	24	18	2	1	2																													
24. *Cometodinium habibii*					35	3	2	48	16	3	2	1						1		48	128	78	65																						
25. *Cyclonephelium* spp.					2		1	11												2	3	2						35	15		2			8		20						20			
26. *Phoberocysta neocomica*					2			5	4	9	6	3	4	2													3	5		4	5			1	3	5	1	2		4	2	4			
27. *Circulodinium distinctum*					6	1	1	50	38	25	21	15	30	2	19	19	3	15	1	35	47	23	12	5	24	40	30	25	47	32	26	5	6	4	30	28	6	2	3	2	35	50	5	3	
28. *Hystrichodinium pulchrum*					2			1	2		3	4	4		5	3	17			1	3	1		1	5	7	2	1	1	2	3				3	2						2		1	
29. *Oligosphaeridium pulcherrimum*					1			1	1	1		1				2	1	1											1							1							1	1	
30. *Wallodinium krutzschii*					1			1		1	1	2	1		2	3				1	3	1	2		2	3	5	4								2		1	1		1	1		1	
31. *Phoberocysta tabulata*					28	4	3	23	35	100	94	90	86	4	43	50	30	3		3	2	1	2	16			42	51	71	26	15	5	12	35	90	115	31	22	18	8	29	30	12	8	17
32. *Cometodinium multispinosum*								1																																					
33. *Cyclonephelium intonsum*								5	2																																				
34. *Oligosphaeridium diluculum*								1	2	15	3	1	4	2																															
35. *Amphorula delicata*								1					1		2						1																								
36. *Wallodinium cylindricum*								2		3	1	1	2	2	4	1	1			1	1	4	3	2		1		4																	
37. *Stanfordella cretacea*								2	4	8		1				2	5						6			2	4				1				1										
38. *Achomosphaera neptuni*								1	1	3	9	8	2	1		1	1	3		4	5	2	3	2	3					1	1			1	2	5		4		1	4	5			
39. *Dapsilidinium warrenii*								2	1		2	1	1		1		1			1		1	2		2	1	2			2	2	1	1		2							3			
40. *Systematophora complicata*								1	1	7	8	25	25		29	16	104	3	1	4	6	3			10	9	30	2	1	3	1	1	1			1		1	1		3	2	4	2	
41. *Heslertonia heslertonensis*										3																																			
42. *Tanyosphaeridium isocalamum*										2	5	4					3		1							1																			
43. *Bourkidinium granulatum*										1						4	1								1	2	1									1	1				1	1			
44. *Systematophora* sp.										52	16	13	14		8	3	55	15	2	12	20	4	3		9	17			5		7	7				5									1
45. *Dichadogonyaulax bensonii*											3	2																																	
46. *Hystrichodinium voigtii*											4	3																																	
47. *Pseudoceratium pelliferum*											8	51	40	2	30	21	42			14		10		18	48	52	30	10	95	27	29	5	4		48	71	6	6	8	4	31	28	2		
48. *Cymososphaeridium* cf. *validum*												1				5	2				2																								

Figure5cont

AGE: TITHON. Late | BERRIAS. E. | BERRIAS. Late | VALANGINIAN Early | VALANGINIAN Late | HAUTERIV ?

LITHOSTRATIGRAPHY: Vendryne Fm | Tesín Limestone | Hradiste Formation

SAMPLES / TAXA	SKb 20	SKb 19	SKb 18	SKb 17	SKb 15	SKb 13	SKb 12	SKb 10	SKb 9	SKb 8	SKb 7	SKb 6	SKb 5	SKb 4	SKb 3	SKb 2	SKb 1	SK 1	SK 2	SK 3	SK 4	SK 5	SK 6	SK 7	SK 9	SK 10	SK 11	SK 12	SK 14	SK 15	SK 16	SK 18	SK 19	SK 20	SK 21	SK 22	SK 24	SK 25	SK 26	SK 27	SK 29	SK 30	SK 32	SK 33	SK 34
49. *Chlamydoporella nyei*												4																																	
50. *Tehamadinium evittii*												3																																	
51. *Kleithriasphaeridium eoinodes*												10	8		12	10	5		2	1		3	2	2	3		4	3		3	1				4	3									
52. *Occisucysta duxburyi*												8								1										3	5	3			2		4	2	1	2	3	3			
53. *Systematophora palmula*												8	10		14	40	25	1	1	3	4	3	1	4	15	28	20	2	4	7	5	2	1		7	6	1	2		1	2	2			
54. *Systematophora silybum*												5				1	12	3	2	23	20	24	28	1	12	16	6	5	1	12	10		8		11	15		8			3	4	4	3	
55. *Hystrichosphaerina schindewolfii*												10	8		9	3	13	1		4	3	2	1	1	7	6	4	1	1	2					4	3						1	1		1
56. *Pseudoceratium gochtii*													10		16					2	2	2			4																				
57. *Muderongia simplex*													1		2					3						18	21	20		14		8	11	10	9				4	2	6	3			
58. *Occisucysta tentorium*															13		5	1																											
59. *Aprobolocysta galeata*																1																													
60. *Ovoidinium diversum*																11																													
61. *Muderongia simplex microperforata*																7	1		1	1		1		3	8	12	11													4		7			1
62. *Exochosphaeridium muelleri*																	1																												
63. *Prolixosphaeridium granulosum*																	1																												
64. *Kleithriasphaeridium corrugatum*																	2	5		2	3	4		4	6	9	8		3	4															
65. *Dissiliodinium globulus*																	1			1																						8			
66. *Oligosphaeridium complex*																	2								2	1	2	1	3	3	1	2			1			1		1	1	2	2	1	1
67. *Muderongia mcwhaei* form A																					1							7													29	28		4	2
68. *Protoellipsodinium spinosum*																					1																								
69. *Tanyosphaeridium* sp. DE																					1	1	3																						
70. *Muderongia pariata*																							1																						
71. *Wrevittia helicoidea*																									1	2	3																		
72. *Circulodinium vermiculatum*																									2	6	15	25	14	11		5	4	3	16	20		2		1	8	12			
73. *Cymososphaeridium validum*																									11	15	14	10	14	11	10	3	4		3	5		3	2	1		3	3		
74. *Dingodinium cerviculum*																										3																			
75. *Dapsilidinium multispinosum*																										1				5	7		3		4										
76. *Muderongia mcwhaei* form B																											8	14													20	32		2	5
77. *Cauca parva*																												2																	
78. *Wallodinium luna*																													1	1											1				
79. *Callaiosphaeridium* cf. *asymmetricum*																															1														
80. *Prolixosphaeridium* cf. *parvispinum*																															3														
81. *Oligosphaeridium? asterigerum*																																		2	2	3		1							
82. *Oligosphaeridium poculum*																																				1			1	1	2	1			
83. *Cribroperidinium confossum*																																					5								
84. *Muderongia staurota*																																										1			
85. *Oligosphaeridium albertense*																																											1		
86. *Oligosphaeridium dividuum*																																											1	1	

Figure6

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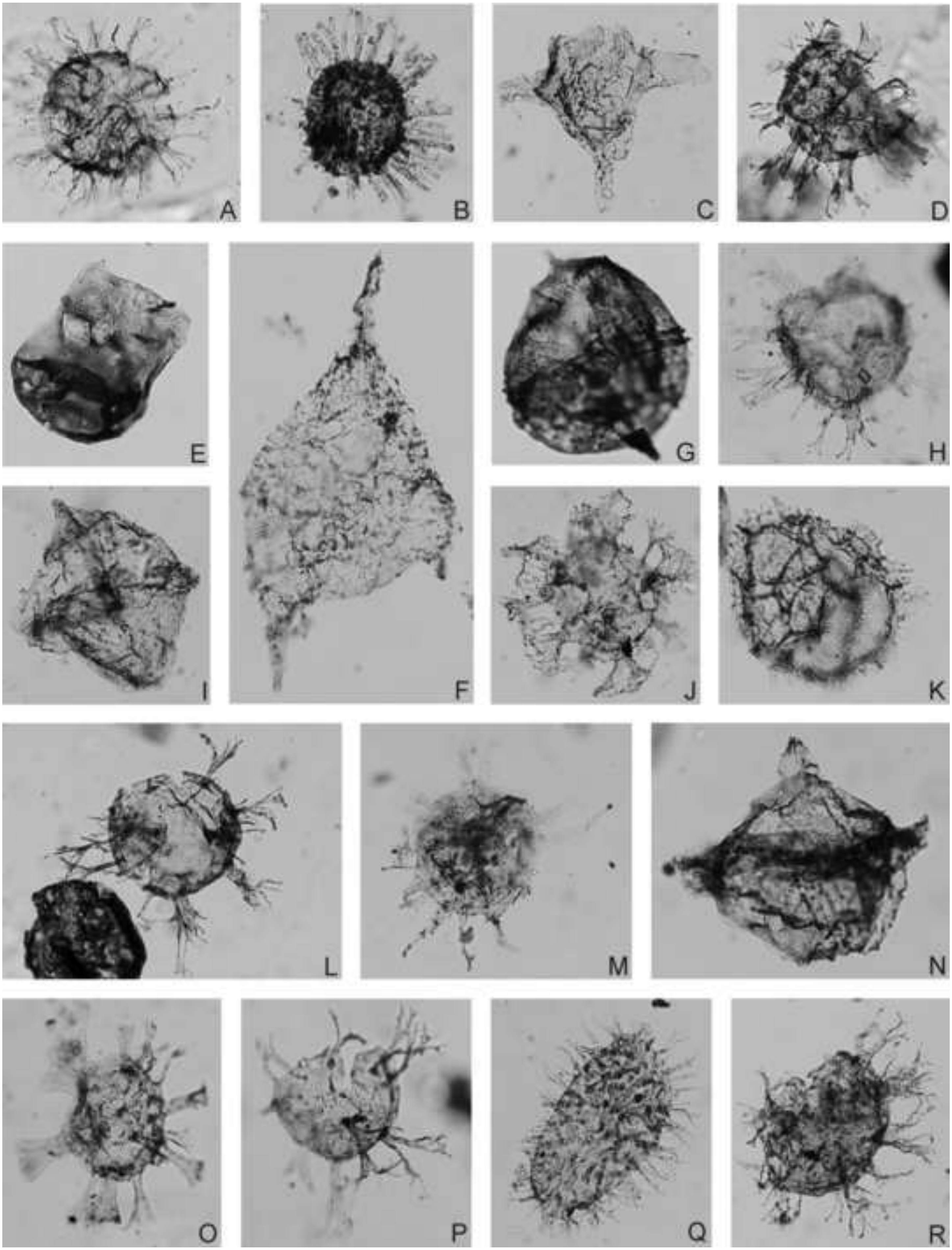

Figure7

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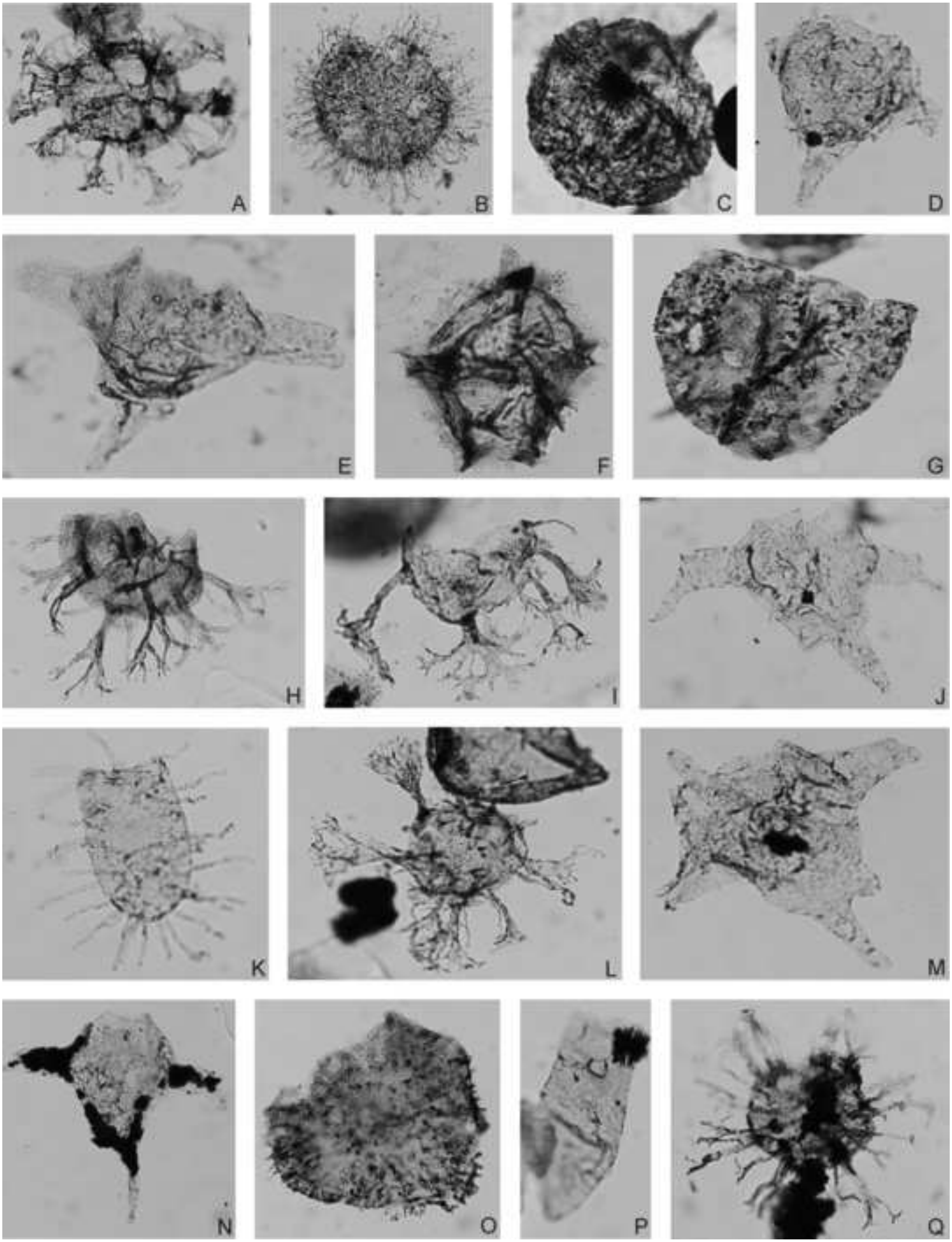

Table

sample	TOC (%)	$\delta^{13}C$ (‰ PDB)	$\delta^{18}O$ (‰ PDB)
SK 33	1.13	0.58	-4.49
SK 28	1.62	0.48	-4.40
SK 26	1.42	0.43	-4.84
SK25	0.70	0.52	-4.75
SK 23	1.09	0.64	-4.51
SK 22	0.82	0.57	-5.23
SK 21	0.47	0.80	-5.39
SK 20	1.10	0.51	-4.69
SK 19	1.00	1.81	-5.63
SL7	1.28	0.91	-5.42
SL5	1.24	0.83	-4.96
SL3	0.91	0.75	-5.10
SL2	0.71	0.81	-4.89
SL1	0.41	0.78	-5.29
SL 0	0.93	0.75	-5.91
SK 18	5.76	0.43	-4.94
SK 17	0.95	0.64	-5.36
SK 16	0.66	0.72	-4.31
SK13	0.85	0.74	-5.01
SK11	0.93	0.62	-4.83
SK9	1.10	0.64	-5.00
SK7	0.65	0.81	-4.93
SK4	0.82		
SK1	0.76		
SKb7	0.66		
SKb13	0.59	not studied	not studied
SKb16	0.91		
SKb19	1.27		